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Design of Optimal MIMO Channel under Line-Of-Sight Environment by using Directional Antenna

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1. Introduction

MIMO system is a technique known as obtaining the high channel capacity. However, the channel capacity is reduced due to the presence of a direct path. Previous studies have shown that high SNR leads to significant capacity enhancement with high correlation environment [1]. Low correlation can be achieved by use of the orthogonality of the received signals in the LOS environment [2,3,4]. This paper presents a directional base station antenna for a distributed transmitting antenna arrangement to achieve both high SNR and low correlation in a LOS environment. We show simulation results of a ray tracing technique and measurement results by indoor environments.

2. MIMO System

Denoting the number of transmit (Tx) and receiving (Rx) antennas by N_t and N_r, the channel capacity of MIMO system is given as eq. (1) without any information of the channel,

$$C = \log_2\left[\det\left(\mathbf{I}_{N_r} + \frac{\gamma}{N_t}\mathbf{H}\mathbf{H}^H\right)\right] \tag{1}$$

where $\mathbf{I}_{Nr}$ is the $N_t \times N_r$ identity matrix, **H** is the normalized MIMO complex channel matrix, γ is the signal-to-noise-ratio (SNR), and ^{H} stands for the complex conjugate transpose of the matrix, respectively. The channel capacity is maximized for $\mathbf{H}\mathbf{H}^H = N_r\mathbf{I}_{N\mathrm{r}}$ because all the eigenvalues of $\mathbf{H}\mathbf{H}^H$ are equal.

We consider a 2 × 2 MIMO system with the distributed antenna arrangement as shown in Fig. 1(a). The Rx array spacing is half wavelength and one Tx antenna is parallel and another is normal to the receiving array with the following condition

$$d_{22} - d_{12} = \frac{\lambda}{2} \qquad (d_{11} = d_{12} = d_{21}) \tag{2}$$

where d_{nm} is the distance between Tx and Rx. Assuming direct paths between Tx and Rx, the normalized free-space channel response matrix is given as $h_{11} = h_{12} = h_{21} = 1$ and $h_{22} = -1$, where h_{ij} is a matrix element of **H** [5]. This antenna configuration can meet the condition to maximize the channel capacity and utilize efficiently LOS components without performance deterioration of MIMO system.

3. Directional Antenna for Distributed System

In the previous section, we consider only a direct path of the channel response. In practical environments, scattered waves always exist. Then we consider scattered components and verify the effect of directional antenna for the distributed and centralized antenna arrangements shown in Fig. 1 by simulations and measurements. We use the 6.2 × 8.8 × 2.7 m^3 room and the fabric of the walls is concrete. Relative permittivity is 6.76, and electric conductivity is 0.0023. Tx and Rx are mounted 1 m above the floor. Antenna spacing between Tx and Rx is 2 m, where the frequency is set to 5 GHz.

An imaging method of ray-tracing is used to simulate the multipath with up to 5 reflections. The directional antenna is used for the Tx side to reduce its half power beam width (HPBW). The omni-directional antenna is used for the Rx side. The channel capacities of the antenna arrangements in Fig. 1 are derived as a function of the K-factor as shown in Fig. 2. K-factor is the ratio of the specular signal power to the multipath signal. For K-factor of 20 dB and SNR of 19 dB, the channel capacity of the distributed antenna system is increased by 65% compared to that of the centralized antenna system. It is clear that the distributed antenna system is superiority to the centralized one.

We verify above simulation results by the measurements under indoor environment. We consider the channel capacity with fixed SNR (= 10 dB) to clarify the effect of low correlation. We use a patch antenna shown in Fig. 3 and a Yagi-Uda antenna shown in Fig. 4 as the directional antennas on the Tx side. Sleeve antennas are used on the Rx side. See [6,7] for the experiment system. The measured channel capacities are shown in Table 1. Eqs. (3),(4) are the MIMO channel matrices normalized by (1,1) elements of the matrix for patch and Yagi-Uda antennas, respectively.

$$H = \begin{bmatrix} 1.00 & 1.14 + 0.40i \\ 1.28 - 0.60i & -1.38 - 0.09i \end{bmatrix} \tag{3}$$

$$H = \begin{bmatrix} 1.00 & 1.05 + 0.28i \\ 1.23 + 0.12i & -1.31 - 0.28i \end{bmatrix} \tag{4}$$

From the measurement results, the channel capacities of the centralized system are reduced by using directional antennas. This is due to high correlation. However, the channel capacities of the distributed system are not reduced. These results show that the proposed system achieve low correlation. For fixed received SNR, transmit powers of the distributed system are saved up to 75% and 84% by using the patch and Yagi-Uda antennas compared to using the sleeve antenna, respectively. Using the Yagi-Uda antenna, the channel capacity of the distributed system is increased by 56% compared to that of the centralized system. The channel matrix is close to the optimal channel matrix to maximize the channel capacity by the use of high directivity antenna in the LOS environment.

4. Conclusion

This paper presented the channel capacity improvement by the distributed antenna arrangement and directional antennas under LOS environment. The simulation results showed that the proposed system provided higher channel capacity than the centralized antenna system. From experimental results, the proposed system achieved low correlation and saved up to 84% of transmit power under indoor environment. The proposed system is expected to provide the optimal channel matrix to maximize the channel capacity by the use of high directivity l antenna.

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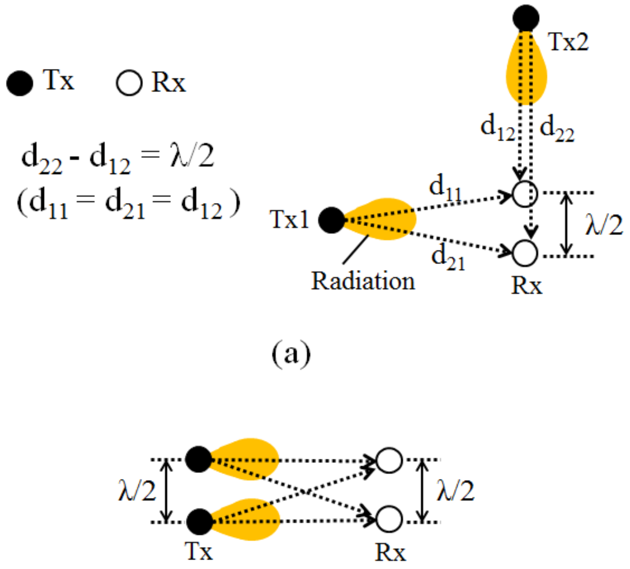


(a)

(b)

Figure 1: Antenna arrangements. (a) distributed antenna system preserving the orthogonality of the received signals, and (b) centralized antenna system.

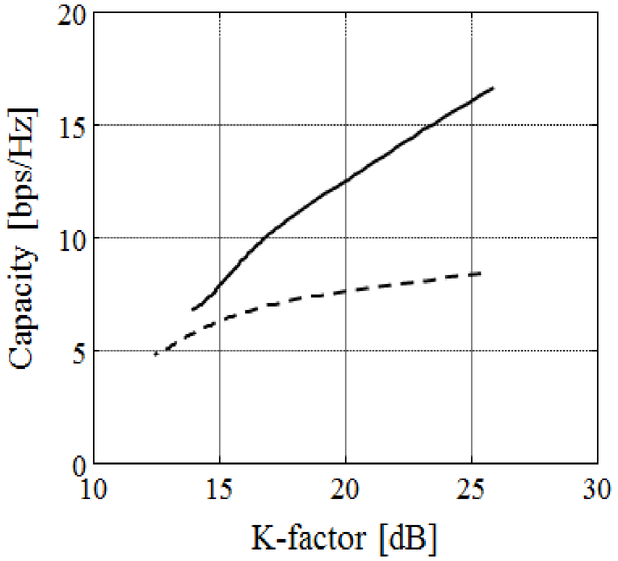
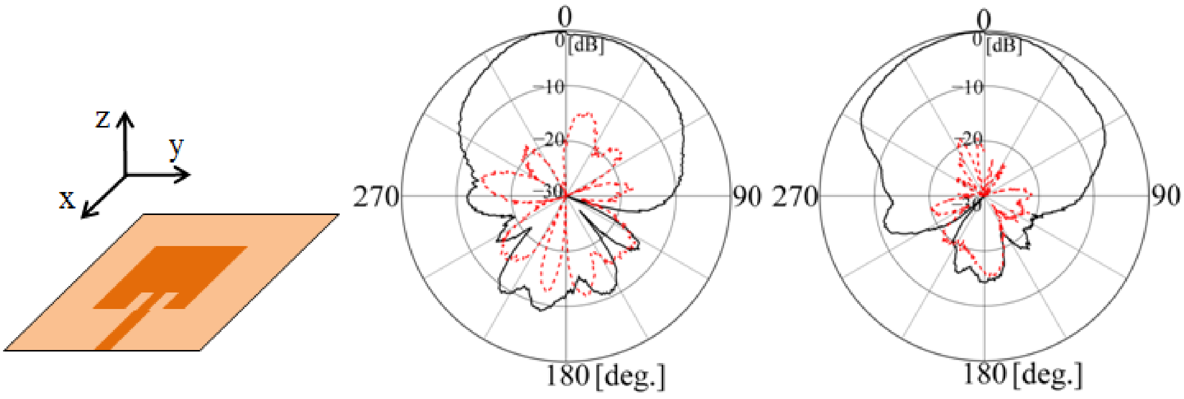
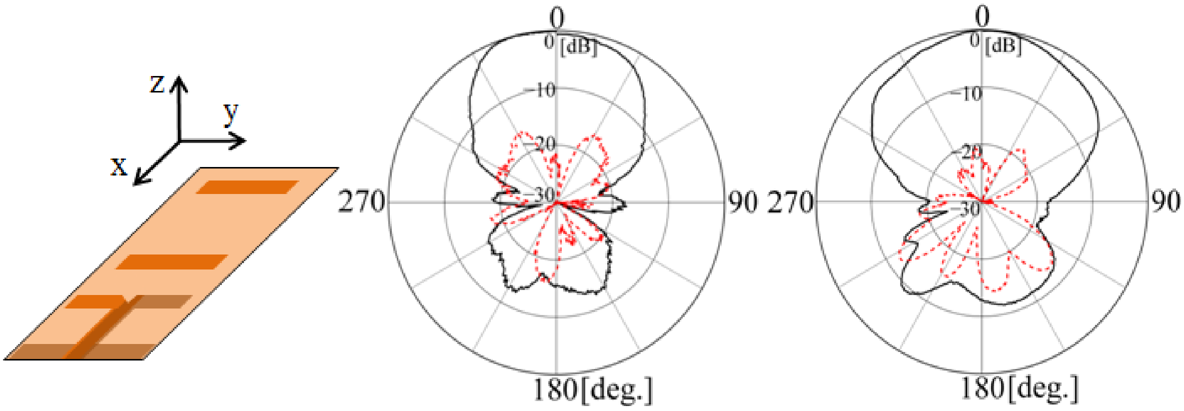


Figure 2: Channel capacities as a function of the K-factor for the antenna arrangements in Fig. 1, solid line is distributed system and dashed line is centralized system.



(a) yz-plane (b) zx-plane

Figure 3: Radiation patterns of the patch antenna, gain: 6 dBi. (a) HPBW: 80°, and (b) HPBW: 90°, black: principal component, red: cross-pol. component.



(a)xy-plane (b) zx-plane

Figure 4: Radiation patterns of the Yagi-Uda antenna, gain: 8 dBi. (a) HPBW: 60°, and (b) HPBW: 90°, black: principal component, red: cross-pol. component.

Table 1: Channel capacity for each antenna configuration (SNR = 10 [dB]).

Tx side	Distributed antenna system in Fig. 1(a) [bps/Hz]	Centralized antenna system in Fig. 1(b) [bps/Hz]
Sleeve antenna	6.64	4.92
Patch antenna	6.84	4.48
Yagi-Uda antenna	6.85	4.40